THE OPPORTUNITY COST OF REGULATING PHOSPHORUS FROM BROILER PRODUCTION IN THE ILLINOIS RIVER BASIN*†

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(ABSTRACT)

The Illinois River Basin in eastern Oklahoma and northwest Arkansas is an example of a region where significant growth in poultry production has been accompanied by water quality problems. The primary concern in the Basin is the problem of phosphorus in runoff that is associated with application of litter to crops. Existing data suggests that there is a continuing decline in the quality of water in the Illinois River, and discussions have focused on developing and implementing a phosphorus standard. The specific objectives of this study are to estimate the reduction in poultry production necessary to achieve the reduction in phosphorus runoff under a set of phosphorus constraints, including soil text phosphorus, and to estimate the opportunity costs of reducing poultry production in the basin under each phosphorus constraint on the economic activity in the watershed. A mathematical programming model that incorporates poultry production and cropping decisions is developed. The parameters for the model are identified, and then it is solved to provide a base solution Model solutions are then developed for the different policy target levels of phosphorus. The model structure is then modified to account for the presence of soil test phosphorus levels and the corresponding limits on soil test phosphorus throughout the basin. This formulation includes current soil test phosphorus throughout the basin. All of the applications assume that the only disposal option for poultry litter is land application. An economic impact assessment of the effects of phosphorus limitations in the basin is also conducted for Arkansas counties only, Oklahoma counties only, and all five affected counties combined.

The key findings of this study are as follows. The limits imposed on phosphorus for the entire basin range from a 20 percent reduction in base-level phosphorus values to target amounts of phosphorus that correspond to a concentration level of 0.02 mg./L. The opportunity cost for the entire basin with the 20 percent reduction is approximately $1.5 million, while the opportunity cost of imposing a phosphorus target consistent with a concentration level 0.02 mg./L. is approximately $7.7 million. The opportunity cost of a phosphorus target consistent with 0.037 mg./L. is roughly $6.5 million. A regional disaggregation of the opportunity costs shows that the majority of the impact lies with the counties in Arkansas. The opportunity cost per ton of litter reduction for the phosphorus restrictions is also calculated. These costs range from $52 per ton of litter reduced to $65 per ton of litter removed. These per-ton costs reflect the assumption that land-based application of litter is the only alternative for disposal of litter generated in the basin and provide a benchmark for comparing alternative options of dealing with litter, including export.

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INTRODUCTION

In recent years, poultry production has become an important component of the economic base for many regions around the United States. These production increases have been almost exclusively in operations now defined as Animal Feeding Operations (AFOs) by the USDA. A corresponding byproduct of poultry production is the generation of poultry litter. Poultry litter contains a variety of nutrients (Govindasamy, Cochran, and Buchberger, 1994), which suggests a potential source of crop nutrients. Moreover, poultry litter can serve as a substitute for commercially produced fertilizers. Production of these nutrients often surpass the amount that can reasonably be utilized by operations on which the litter is produced, resulting in export of the nutrients to nearby farms and ranches and potentially increasing the possibility for nutrient runoff into water sources, according to recent studies on water quality (Gollehon et al., 2001; Kellogg et al., 2000). Some researchers (Govindasamy, Cochran, and Buchberger, 1994; Govindasamy and Cochran, 1995a, 1995b, and 1998) have argued that high concentrations of poultry litter may result in litter applications where nutrient requirements are exceeded and excessive nutrients in surface and groundwater become a problem. For example, increased application of poultry litter could lead to concerns about the environmental impacts of increased nitrate, phosphorus, and bacteria levels in water supplies (Sharpley et al., 1994). The presence of phosphorus in agricultural runoff is thought to be an important source of eutrophication (Sharpley et al., 1994).

Several contemporary research pieces have investigated the impacts of limiting land application of animal nutrients to attempt achieving water quality goals at the local level (Ribaudo et al., 2001; Roe et al., 2002). Similar analyses have examined impacts at the national level (EPA, 2001; FAPRI, 2001; USDA-NRCS, 2002). The attendant water quality problems resulting from the presence of phosphorus in runoff from agricultural nonpoint sources clearly suggests the need for developing phosphorus management policies (Meo et al., 2002). These policies should reflect a combination of factors, including a balance between crop needs and the total available soluble phosphorus, transport processes for surface and groundwater, erosion and runoff susceptibility of soils, and proximity to eutrophication-sensitive surface waters. Kaplan, Johansson, and Peters (2004) used a mathematical programming approach to examine the implications of a policy whereby only CAFOs (most poultry operations are CAFOs) meet nutrient constraints such as plant nutrient uptake. They allowed crop and animal production decisions to respond to price effects precipitated by these constraints, but posited that their analysis could not reveal how individual operations would benefit or be harmed by the constraints.

An example of a region where significant growth in poultry production has been accompanied by water quality problems is the Illinois River Basin in eastern Oklahoma and northwest Arkansas. (A map of the Illinois River Basin is presented in Figure 1.) The Illinois River Basin covers an area of 433,160 hectares; 54 percent of the total basin is located in Oklahoma. The portion of the Illinois river in Oklahoma is a popular tourist and recreation attraction and was the first river designated as wild and scenic by the state of Oklahoma. Annually an estimated 180,000 people float the Illinois River by canoe, raft, or kayak while approximately 350,000 enjoy swimming, fishing, camping, hiking, birding, and hunting opportunities (Meo et al., 2002). The Illinois River is a source of drinking water for several municipalities and irrigation water for farms and nurseries and provides a habitat for several state and federal threatened and endangered species (Bality et al., 1998). Tourism is an important component of the economic base in the Basin, especially the portion in Oklahoma. A substantial amount of income is also derived from agriculture, plant nurseries, forestry, and gravel and limestone mining. Agricultural activities include cattle ranching and poultry operations; sales from broiler production alone increased from $171.4 million to $291.7 million over the period 1982 to 2002 (USDA, 2004).

The historical evolution of water policy in the Illinois River Basin with respect to Arkansas and Oklahoma is highlighted with controversy in recent periods (Meo et al., 2002). For example, a controversy in the late 1980s and early 1990s involved the discharge of municipal waste water into the Illinois River by the City of Fayetteville, Arkansas. Given the river's natural heritage designation in Oklahoma, increased wastewater discharges from sources in Arkansas triggered a lawsuit by Oklahoma

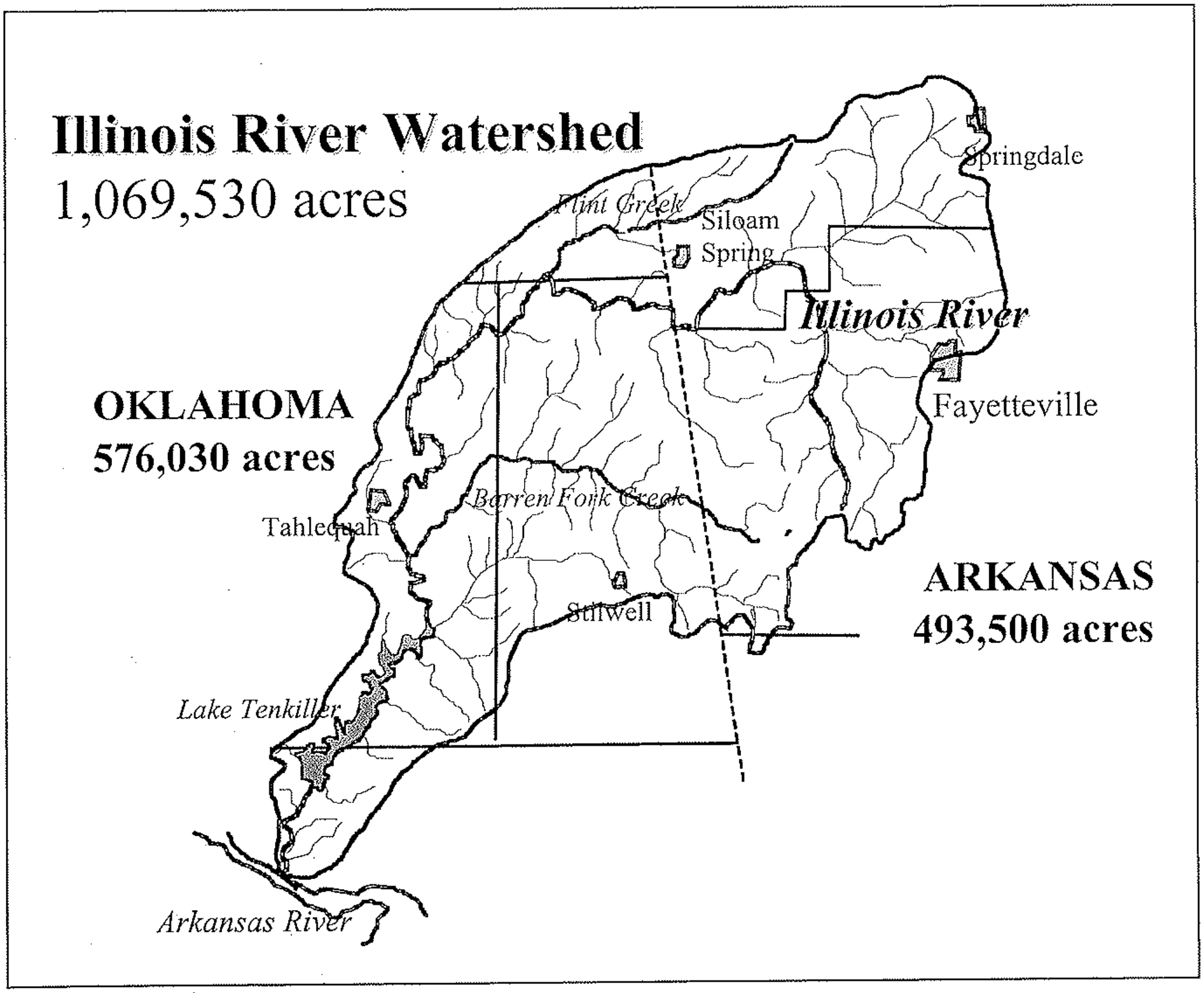

Figure 1: Illinois River Basin

(Bality et al., 1998). This legal action resulted in a U.S. Supreme Court decision in 1992 that resolved the conflict in favor of Arkansas. The lawsuit was based on the proposition that Fayetteville must meet Oklahoma's water quality standards at the state line, but it was concluded that existing evidence did not prove that the city of Fayetteville violated Oklahoma water quality standards. In 1996 a report on Tenkiller Lake, which is downstream on the Illinois River, contained a recommendation for phosphorus reductions in the Illinois River Basin (Storm et al., 1996). In 1997, the Arkansas – Oklahoma River Compact Commission established a goal to reduce phosphorus in the Basin by 40 percent.

The status of water quality in the Illinois River Basin continues to be a concern. Existing data indicate that the Illinois River's scenic river status in Oklahoma is seriously threatened by excess nutrients, including phosphorus. Moreover, available data indicate nutrient loads are increasing (Vieux and Moreda, 2003). The sources of phosphorus include sewage treatment plant discharges and agricultural and urban/residential runoff (Vieux and Moreda, 2003). The continual decline in water quality has led to discussions focused on developing and implementing a phosphorus standard.

The purpose of this paper is to identify the sources and estimate the opportunity costs of the various phosphorus limitation proposals that have been proposed to address the decrease in water quality. Opportunity costs would come in the form of forgone agricultural returns resulting from limited application of poultry litter and decreased poultry numbers in the study area as a consequence of phosphorus limits. The analysis will examine a set of proposed target levels for the Illinois River Basin, including an Oklahoma Scenic Rivers Commission standard of 0.020 mg/L and a target level of 0.037 mg/L, which is designed to control algal growth. The state of Oklahoma has decided to adopt the target level of 0.037 mg/L. The policy discussions for controlling phosphorus have also included efforts to monitor and control soil test phosphorus levels in the river basin. For example, Oklahoma has placed limits on the ability to land apply poultry litter based upon the amount of soil test phosphorus per acre. The impact of policies imposing limitations on soil test phosphorus levels throughout the basin as an alternative to reduced levels of phosphorus loads in the Illinois River Basin are examined. The latter analysis will include an examination of the corresponding amounts of phosphorus that appears in runoff.

The main question in this case is whether the soil test phosphorus limits are sufficient to bring about the necessary reductions in basin-wide levels of phosphorus. It is assumed throughout these analyses that all litter generated in the river basin is disposed of by land application within the river basin. Therefore, phosphorus levels in runoff may be reduced primarily by curtailing poultry production in the river basin.

The specific objectives of this study are to:

- Estimate the reduction in poultry production necessary to achieve the reduction in phosphorus runoff under each of the aforementioned constraints, including soil test phosphorus and
- Estimate the opportunity costs of reducing poultry production in the watershed under each phosphorus constraint on the economic activity in the watershed.

A mathematical programming model that incorporates poultry production and cropping decisions is developed in the next section. The parameters for the model are identified and then it is solved to provide a base solution. Model solutions are then developed for the different policy target levels of phosphorus. The model structure is then modified to account for the presence of soil test phosphorus levels and the corresponding limits on soil test phosphorus throughout the basin. This formulation will include current soil test phosphorus data throughout the basin. All of these applications assume that the only disposal option for poultry litter is land application. An economic impact assessment of the effects of phosphorus limitations in the basin is also conducted for Arkansas counties only, Oklahoma counties only, and all five effected counties combined.

MODEL STRUCTURE

Several studies have examined the economic and environmental impacts of poultry litter generation, fertilizer use, and disposal (Govindasamy and Cochran, 1995, 1998; Govindasamy, Cochran, and Buchberger, 1994; Xu, Prato, and Fulcher, 1993). A common feature of the model structures used in these studies is that poultry litter is treated as a factor of production. The models used by Govindasamy and Cochran (1995a, 1995b, 1998) and Govindasamy, Cochran and Buchberger (1994) focus more on poultry litter applications and pay less attention to nutrients, particularly nitrogen and phosphorus.

Poultry litter is introduced into the model structures used in these studies through a balance equation that traces the use of poultry litter. One part of the equation describes the quantity of poultry litter produced in the watershed while other terms quantify uses of poultry litter. The uses are the amounts of litter applied to crops in the region of study as well as the amount of litter transported from the watershed for use in other regions. No explicit consideration is given to nutrient demands. Xu, Prato, and Fulcher (1993) explicitly model the demand for nutrients and also consider the tradeoffs between litter as a source of crop nutrients and commercial fertilizers. The supply sources of litter are treated as exogenous in all of these models. Among other things, it is assumed that the generation of poultry litter is proportional to poultry production. This implies that reductions in poultry litter require a proportional reduction in broiler production. Schwabe (2000) uses a mathematical programming model to evaluate alternative management strategies for reducing nutrient loadings in the Neuse River, which is located in eastern North Carolina.

An important extension of the modeling structures cited above is to make the supply of nutrients and hence the generation of poultry litter endogenous. This can be accomplished by explicitly incorporating broiler production decisions. The outcome of this extension is an integrated modeling structure that offers the advantage of allowing the flexibility of broiler production responses to be reflected in the opportunity costs of various situations. This integrated framework also provides a more realistic perspective of the opportunity cost of environmental policies.

The modeling framework used in this paper incorporates poultry production and cropping decisions as well as decisions pertaining to litter application. This framework is used to measure the opportunity cost of the different target levels (and related policies) for phosphorus from poultry litter. Assume that profit maximization is the decision criterion within the river basin. It is then possible to identify a profit level in the absence of phosphorus restrictions. Implementation of a restriction on phosphorus usually causes profits to be lower in the presence of such a restriction. This reduction in profits represents the opportunity cost of a particular restriction. Thus if Λ denotes the opportunity cost of a target level of phosphorus, then:

$$\Lambda = \overline{\pi} - \hat{\pi} \tag{1}$$

where: $\overline{\pi}$ ≡ profits in the absence of a target level for phosphorus, and

$\hat{\pi}$ ≡ profits with a target level of phosphorus in place.

The development of the integrated modeling structure should reflect, as closely as possible, the realities of broiler production, litter generation and disposal, and cropping activities. The majority of broilers are produced under some type of contract arrangement between a poultry company (integrator) and a grower. The integrator provides the birds and feed and supervises the growth of the birds through a "service person." (Note that the integrator retains ownership of the birds.) The grower provides housing, equipment, and labor. In addition, the grower is also responsible for waste management. In many cases, the contracts between integrators and growers call for compensation or a price to be paid per unit of weight. The contract may also include incentives to encourage efficient production. A more detailed discussion and analysis of these contracts is beyond the scope of this paper. The interested reader should consult Knoeber and Thurman (1995). Within each production region, broiler production is defined on the basis of a "contract broiler production unit", where each unit, or production house, is assumed to be homogenous throughout the region.

The profitability levels are based on a mathematical programming model structure. Let the index i ($i = 1, \ldots, I$) denote the type of crop produced and k ($k = 1, \ldots, K$) the area or region of production. Let the index z, where $z = 1, 2$, denote the separate political jurisdictions where 1 equals Oklahoma and 2 equals Arkansas. The index n ($n = 1, 2$) is used to denote the nutrient for crops, either phosphorus or nitrogen. In addition, the following notation is used:

P_i ≡ price for crop i;

L^z_{ki} ≡ total amount of land for crop i in region k;

Ω^z_{ki} ≡ productivity of crop i, region k;

c^z_{ki} ≡ per-unit cost of crop i produced in region k;

η^z_k ≡ amount of manure generated per unit of broiler weight for region k;

e^z_{ki} ≡ cost of spreading a unit of poultry litter on crop i in region k from broiler production in region k;

θ^z_{kin} ≡ amount of nutrient n in a unit of poultry litter from a broiler production unit spread on crop i in region k;

Γ^z_k ≡ response matrix coefficient for phosphorus in runoff in production region k, political jurisdiction z;

r^z_{1k} ≡ profit margin for a unit of broiler output from a broiler production unit in region k;

m^z_{ki} ≡ profit margin for crop i produced in region k $\left(m^z_{ik} \equiv p_i\Omega^z_{ki} - c^z_{ki}\right)$;

a^z_{kin} ≡ amount of nutrient n needed to produce a unit of crop i in region k;

q^z_k ≡ number of birds in a broiler production unit in region k_i;

J^z_k ≡ number of broiler production units in region k;

W^z_k ≡ weight for an individual bird in a production unit in region k;

M^z_{ki} ≡ amount of poultry litter applied to crop i in production area k, political jurisdiction z;

F^z_k ≡ amount of feedstuff used for an individual bird in a production unit in region k;

G ≡ total amount of phosphorus from runoff;

β^z_{ki} ≡ proportion of phosphorus not used by crop i in region k that becomes runoff or available for runoff; and

V_k^z = total amount of poultry produced in region k, political jurisdiction z;

α^z_{kin} ≡ proportion of applied nutrient n that is available for use by crop i in region k.

Economic profits from broiler production and cropping activity (in the absence of an environmental policy) are determined by the following integrated mathematical programming model:

$$max\ \bar{\pi} = \sum_{z=1}^{2}\sum_{k=1}^{K} r^z_k V^z_k + \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I} m^z_{ki} L^z_{ki} - \sum_{z=1}^{2}\sum_{k=1}^{K}\sum_{i=1}^{I} e^z_{ki} M^z_{ki} \qquad (2)$$

subject to:

$$W^z_k = \phi^z_{1k} + \phi^z_{2k} F^z_k + \phi^z_{3k}\left(F^z_k\right)^2 \qquad (3)$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$V^z_k = J^z_k q^z_k W^z_k \qquad (4)$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$\sum_{i=1}^{I} L_{ki}^{z} \leq \overline{L}_{k}^{z} \tag{5}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$\eta_{k}^{z} V_{k}^{z} - \sum_{i=1}^{I} M_{ki}^{z} = 0 \tag{6}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$a_{kin}^{z} L_{ki}^{z} = \alpha_{kin}^{z} \left(\theta_{kin}^{z} M_{ki}^{z}\right) \tag{7}$$

$$(z = 1, 2)$$

$$(k = 1, \ldots, K)$$

$$(i = 1, \ldots, I)$$

$$(n = 1, 2)$$

$$\sum_{z=1}^{2} \sum_{k=1}^{K} \sum_{i=1}^{I} \Gamma_{k}^{z} \left[\beta_{ki}^{z} \left(1 - \alpha_{ki1}^{a}\right) \left(\theta_{ki1}^{z} M_{ki}^{z}\right)\right] - G = 0. \tag{8}$$

The objective function equation (2) is defined as economic profit where the variables are broiler live weight produced, land use activities and litter applications to crops. It should be noted that equation (2) explicitly represents the cost of spreading litter. The components of the constraint set can be divided into two logical components. The set of constraints (3) and (4) are concerned with broiler production. The set of constraints (5) through (8) is concerned with cropping activities and the disposition of poultry litter. The last constraint is concerned with tracking phosphorus available for runoff from nonpoint sources throughout the study region. These constraints are explained in more detail in the following paragraphs.

The production of broilers in this model is based on the notion of a "broiler production unit." This definition includes a set number of birds produced in the unit along with a return per unit of live weight.

The weight gain for broiler production is usually stated in terms of a biological or growth response function (Pestie, Arreas, and Miller 1985; Miller, Arreas, and Pesti, 1986; and Gonzalez-Alcorta, Dorfman, and Pesti, 1994). The development of these response functions is based on test trials where a growth function or biological response function is estimated for a single bird (Gonzalez-Alcorta, Dorfman, and Pesti, 1994).

The model formulation for broiler production draws from the formulations reported in Gonzalez-Alcorta, Dorfman, and Pesti. (1994). Equation (3) is a biological response function that shows weight gain to be a function of feed intake. Feed intake is an implicit function of changes in metabolizable energy levels and protein levels in the broiler diet. Equation (3) is assumed to have positive but diminishing marginal returns. Finally, equation (4) is a relationship that tabulates the total weight of broilers produced in the region.

The remaining components of the constraint set are concerned with cropping activities and poultry litter disposition. Production regions based on political sub-jurisdictions or other geographic units are explicitly represented in the model. Constraint (5) represents restrictions on land availability. (It is also possible that this set of constraints could include other factors such as participation in the agricultural commodity reserve programs.) The variable L_{ki}^{z} represents amounts of land in crop-related activity.

Constraint (6) is a balance equation reflecting the sources and disposition of poultry litter. The first term on the left-hand side of constraint (6) denotes the amount of litter generated from broiler production. The second term shows the amount of litter spread on the different crops.

Equations (7) and (8) show a set of relationships that pertain to the supply and demand of the nutrients phosphorus and nitrogen applied to crops in the model as well as the amount of phosphorus lost to runoff. In particular, equation (7) shows the equality of the supply of nutrients and the corresponding demand for each production region. This equation shows that the source of nutrients is derived from poultry litter.

The nutrient formulations use a structural process design and nutrient balance approach that is similar to the formulations used by Xu et al. (1993) and Schwabe (2000). Crop production activities and land-based disposal of litter is represented by a set of discrete production activities with unit activity vectors. It is assumed that part of the nutrients applied to the ith crop in region k, political jurisdiction z, are taken up by the crops while the remaining portion is lost to runoff. The amount of nutrient lost to runoff is assumed to be proportional to the amount of nutrient not taken up by crops. Constraint (8) is concerned with tracking nutrients from cropping activities that find their way into runoff.

The final constraint in the model is concerned with the implementation of phosphorus limitations in the Illinois River Basin. This constraint is written as:

$$G \leq \overline{G} \qquad (9)$$

where the right-hand side of equation (9) reflects the upper bound for phosphorus in the Illinois River Basin.

EMPIRICAL APPLICATION AND RESULTS

This model is implemented for the Illinois River Basin. The production regions are defined on the basis of a set of counties located in the river basin. The counties in Oklahoma are Adair, Delaware, and Cherokee. The counties in Arkansas are Benton and Washington. Within each county, broiler production is defined on the basis of a "contract broiler production unit." These units are assumed to be homogenous throughout each production region. (A more in-depth discussion of these is presented below.) The level of aggregation for cropping activities is assumed to be at the production region or county level.

The biological response function for broiler weight gain is:

$$W_k = -0.2068 + 4.3219F_k - 2.0507\,F_k^2\,. \qquad (10)$$

This function was adapted from functions developed in Gonzalez-Alcorta, Dorfman, and Pesti (1994). A detailed development of this function is given in the appendix.

The procedures used to develop the parameters for this model are described in the following paragraphs. Information on poultry production data is presented in Table 1. The poultry returns data are derived from information presented by Doye, Berry, and Norris (1993) for a "contract broiler production unit." A broiler production house is assumed to raise six batches of chicks each year with each batch consisting of 25,000 chicks with a 4 percent death loss and 1 percent condemnation. (This amounts to 23,712 birds per batch.) As noted previously, the chicks, feedstuff, medication, and hauling are provided by the integrator. The birds are assumed to be sold at 4.69 pounds, the average live weight of broilers, at a base pay of for $0.045 per pound (USA Poultry). The total costs per pound live weight of raising the birds must be subtracted from the base pay value. In addition, the return above all costs must be adjusted to reflect the fact that litter disposal has been treated as a separate activity in the model. The adjusted returns above costs, r_{1k}, was found to be approximately $0.011 per pound of live weight or $22.4818 per ton of live weight. A "litter generation" coefficient and the corresponding cost of litter removal and land application per ton are also shown in Table 1. The nutrient loadings for each ton of poultry litter shown in Table 1 are taken from Smith et al. (1996).

Table 1
Broiler Production Data

Broiler Returns:
r_{1k} = $22.4818/ton
Litter Generation and Removal:
$\eta_k = 0.5833826$
e_{ki} = $8.066/ton
Nutrient Loadings for Litter:
phosphorus ($n = 1$) $\theta_{ki1} = 50$ pounds/ton litter
nitrogen ($n = 2$) $\theta_{ki2} = 60$ pounds/ton litter

Data on poultry production units for the production areas or counties included in this study are shown in Table 2. The data for 1997 were calculated using information from the Census of Agriculture for 1997. Data for the production areas showing broiler production, litter generation, and the related nutrients nitrogen and phosphorus are shown in Table 3 and used for the model parameters.

Table 2
Poultry Production Units

County	1997
Adair (OK)	103
Cherokee (OK)	20
Delaware (OK)	185
Benton (AR)	807
Washington (AR)	742
Total	1,857

Source: Census of Agriculture, 1997

Table 3
Broiler Production, Litter Generation, and Related Nutrients for 1997

County	Number of Broilers	Broiler Live Weight (tons)	Tons of Litter	Tons of Nitrogen	Tons of Phosphorus
Adair (OK)	14,622,238	34,288	20,003	600	500
Cherokee (OK)	2,897,415	6,794	3,963	118	99
Delaware (OK)	26,314,540	61,706	35,998	1,079	899
Benton (AR)	114,881,331	269,392	157,158	4,714	3,928
Washington (AR)	105,565,996	247,548	144,415	4,332	3,610
Total	264,281,520	619,728	361,537	10,843	9,036

The crops represented in the mathematical programming model for each of the Illinois River Basin counties are shown in Table 4. Production and economic returns data for the crops are shown in Table 5. The information included in Table 4 indicates the nutrient demands for the different crops produced in each county. Production and return data were taken from the Oklahoma State University Enterprise Budget Generator (Kletke, 1979). The base year in the optimization is 1999. The data shown in Table 3 were used as a basis to calibrate the initial base solution for the optimization model.

Table 4
Cropping Activities for Illinois River Basin Counties

Crop	Adair	Cherokee	Delaware	Benton	Washington
Bermuda Grass	$n = 1$	$n = 1$	$n = 1$		
& Pasture ($i = 1$)	$n = 2$	$n = 2$	$n = 2$		
Wheat for Grain ($i = 2$)	$n = 2$	$n = 2$	$n = 2$		
Native Grass Pasture ($i = 3$)	x	x	x	x	x
Soybeans ($i = 4$)	$n = 1$	$n = 1$	$n = 1$		
Alfalfa Hay ($i = 5$)	x	x	x	x	x
Fescue Hay	$n = 1$	$n = 1$	$n = 1$	$n = 1$	$n = 1$
& Pasture ($i = 6$)	$n = 2$	$n = 2$	$n = 2$	$n = 2$	$n = 2$

$n = 1$ – phosphorus, $n = 2$ – nitrogen, x = no specified nutrient demand.

Table 5
Production and Economic Returns Parameters

	Bermuda Grass Hay and Pasture ($i = 1$)	Wheat for Grain* ($i = 2$)	Native Grass Pasture** ($i = 3$)	Soybeans ($i = 4$)	Alfalfa Hay*** ($i = 5$)	Fescue Hay and Pasture ($i - 6$)
Net returns per acre	$m^z_{k1} = \$156.75$/acre	$m^z_{k2} = \$36.23$/acre	$m^z_{k3} = \$6.29$/acre	$m^z_{k4} = \$77.33$/acre	$m^z_{k5} = \$128.50$/ acre	$m^z_{k6} = \$39.95$/acre
Production	Bermuda Hay $\Omega^z_{k1} = 2.5$ tons/ acre Pasture $\Omega^{z'}_{k1} = 6$ AUMS[1]/ acre	Wheat $\Omega^z_{k2} = 29$ bu[2]/acre Small Grazing Pasture $\Omega^{z'}_{k2} = 0.9$ AUMS/ acre	$\Omega^z_{k3} = 1.38$ AUMS/ acre	$\Omega^z_{k4} = 29$ bu/acre	$\Omega^z_{k5} = 3.25$ tons/ acre	Fescue Hay $\Omega^z_{k6} = 0.75$ tons/ acre Fescue Grazing Pasture $\Omega^{z1}_{k6} = 6.50$ AUMS/ acre
Nutrient Demand	Phosphorus $a^z_{k11} = 40$ lbs/ acre Nitrogen $a^z_{k12} = 275$ lbs/ acre	Nitrogen $a^z_{k22} = 56$ lbs/acre		Phosphorus $a_{k41} =$ 30 lbs/acre		Phosphorus $a^z_{k61} =$ 40 lbs/acre Nitrogen $a_{k62} =$ 180 lbs/acre
Production Counties	$k = 1$ Adair $k = 2$ Cherokee $k = 3$ Delaware	$k = 1$ Adair $k = 2 =$ Cherokee $k = 3$ Delaware	$k = 1$ Adair $k = 2$ Cherokee $k = 3$ Delaware $k = 4$ Benton $k = 5$ Washington	$k = 1$ Adair $k = 3$ Delaware	$k = 1$ Adair $k = 2$ Cherokee $k = 3$ Delaware $k = 4$ Benton $k = 5$ Washington	$k = 1$ Adair $k = 2$ Cherokee $k = 3$ Delaware $k = 4$ Benton $k = 5$ Washington

* Small grain for clay and loam soils with custom harvest. **Deferred grazing, good to excellent conditions. ***Clay and loam soils, usually classes I and II, owned equipment custom hauling.
[1] AUMS = Animal Unit Months. This is defined as the amount of forage to supply one month's grazing for one 1,000 pound beef/dairy animal.
[2] bu = bushel

The relationship between the amount of nutrients applied and the amount for crop uptake is assumed to be a proportional relationship, as shown in Equation (7). The phosphorus uptake coefficient used in this model is 0.33 and the coefficient for phosphorus remaining in the soil is 0.67 (Dr. Phillip A. Moore, USDA/ARS, personal communication). It is also assumed that the amount of phosphorus in runoff is proportional to the amount of phosphorus not used for crop uptake and remaining in the soil as shown in equation (8). Dr. Moore has suggested a value of 0.08 for this coefficient. The total amount of phosphorus in runoff in the Illinois River Basin is adjusted to reflect the percentage of land in each of the five counties included in this study that lie in the Illinois River Basin. These percentages are shown in Table 6.

Table 6
County Lands in the Illinois River Basin

County	Percentage of the County in the Illinois River Basin
Adair (OK)	80
Cherokee (OK)	50
Delaware (OK)	10
Benton (AR)	40
Washington (AR)	50

The range of limits set on phosphorus in runoff for the Illinois River Basin is shown in Table 7. These limits are assumed to correspond to the maximum mass loadings of phosphorus in the Illinois River as measured by monitoring devices located in the Illinois River south Tahlequah, Oklahoma. The estimated base value for phosphorus is 153 tons per year. These values are based on a modeling exercise that is described in Meo et al. (2002) and Vieux and Moreda (2003). The mathematical programming model was solved using the set of target levels shown in Table 7 for $\overline{G}$ in constraint (9).

The remainder of this section is concerned with an analysis of using the set of target levels shown in Table 7. These discussions are focused on the opportunity costs and corresponding impacts regulating phosphorus will have on the regional economy throughout the Illinois River Basin. No discussion on the processes governing the transport and bioavailability of P in surface runoff from agriculture landscapes is provided since this is beyond the scope of this paper. This type of discussion for the Illinois River Basin can be found in Viieux and Moreda (2003).

Table 7
Phosphorus Reductions

Allowed Phosphorus Level (Tons)	Required Phosphorus Reduction (Tons)	Nature of Reduction
153	----	----
122	31	20% below base
77	77	50% below base
56	97	0.05 mg/L
41	112	0.037 mg/L
31	123	80% below base
22	131	0.02 mg/L

The opportunity costs for a range of phosphorus restrictions in the Illinois River Basin are shown in Table 8. The limits imposed on phosphorus for the entire range from a 20 percent reduction in base-level phosphorus values to a target amount of phosphorus that corresponds to a concentration level of 0.02 mg./L. The opportunity cost for the entire basin with the 20 percent reduction is approximately $1.5 million, while the opportunity cost of imposing a phosphorus target consistent with a phosphorus concentration of 0.02 mg./L. is approximately $7.7 million. The opportunity cost of a phosphorus target consistent with 0.037 mg./L. is roughly $6.5 million. The opportunity cost shown in Table 8 increases by 517 percent over the range of phosphorus reductions shown in Table 8 for the Illinois River Basin.

A regional disaggregation of the opportunity costs is also shown in Table 8. Consider first the impacts on the portions of the river basin located in Oklahoma. The opportunity cost of the basin-wide restriction for the Oklahoma region of the Illinois River Basin ranges from $402,000 to approximately $554,000. This represents roughly a 38 percent increase in the opportunity cost as the phosphorus limit becomes more restrictive. It is also interesting to note that the largest impact in Oklahoma of the basin-wide phosphorus restrictions lie with Adair County over the entire range of phosphorus limits. The opportunity cost for Cherokee County becomes nonzero when the phosphorus limit corresponding to a concentration level of 0.05 mg/L. is imposed on the River Basin. According to the results reported, Delaware County, in contrast, is not impacted by the basin-wide phosphorus restrictions.

Table 8
Opportunity Cost of Phosphorus Restrictions in the Illinois River Basin

	20 % Reduction	50 % Reduction	0.05 mg/L Target	0.037 mg/L Target	80 % Reduction	0.02 mg/L Target
Oklahoma						
Adair County	$402,386	$402,386	$524,794	$524,794	$524,794	$524,794
Cherokee County	0	0	29,253	29,253	29,253	29,253
Delaware County	0	0	0	0	0	0
Total	$402,386	$402,386	$554,047	$554,047	$554,047	$554,047
Arkansas						
Benton County	0	0	1,040,960	2,081,089	2,799,069	3,369,132
Washington County	1,093,921	3,639,425	3,816,254	3,816,254	3,816,254	3,816,254
Total	$1,093,921	$3,639,425	$4,857,214	$5,897,343	$6,615,323	$7,185,386
River Basin Total	$1,496,307	$4,041,811	$5,411,261	$6,451,390	$7,169,370	$7,739,433

Opportunity costs of the region of the Illinois River Basin located in Arkansas are shown to range from $1.1 million to $7.2 million, which represents an approximate 650 percent increase in opportunity cost as the phosphorus limit becomes more restrictive for the Illinois River basin (Table 8). Table 8 shows that most of the opportunity costs for the basin-wide phosphorus limits lie with the region of the basin located in Arkansas. Initially 73 percent of the opportunity costs lie with the Arkansas region and increases to 94 percent when the most restrictive phosphorus limit is imposed on basin-wide activity. Initially all of the opportunity costs are shown to lie with Washington County. The magnitude of the opportunity costs in Benton County approach the size of the opportunity costs observed for Washington County as the basin-wide phosphorus limits become more restrictive.

An additional perspective of the adjustment process across the Illinois River Basin with more restrictive limits on basin-wide phosphorus levels is presented in Table 9, which shows poultry production in the Illinois River Basin. Table 9 shows that the largest amount of poultry production of the three counties in the Oklahoma portion of the River Basin is in Delaware County. However, this county is not impacted by the basin-wide phosphorus restrictions: only 10 percent of the land area in Delaware County is located in the Illinois River Basin. This is a much smaller area relative to the other counties in the Basin. In addition, the crops produced in Delaware County exhibit a high enough demand for phosphorus as a nutrient to support the poultry litter applications observed in the model solutions.

Table 9
Poultry Production for the Illinois River Basin
(Tons of Live Weight)

	Base	20 % Reduction	50 % Reduction	0.05 mg/L Target	0.037 mg/L Target	80 % Reduction	0.02 mg/L Target
Oklahoma Counties							
Adair	33,442	10,805	10,805	5,958	5,958	5,958	5,958
Cherokee	6,494	6,494	6,494	4,848	4,848	4,848	4,848
Delaware	60,065	60,065	60,065	60,065	60,065	60,065	60,065
Total	100,001	77,364	77,364	70,871	70,871	70,871	70,871
Arkansas Counties							
Benton	250,231	250,231	250,231	191,672	133,159	92,768	60,700
Washington	214,685	153,146	9,948	0	0	0	0
Total	464,916	403,377	260,179	191,672	133,159	92,768	60,700
Two-State Total	564,918	480,741	337,543	262,543	204,030	163,639	131,571

The data in Table 9 shows the impacts resulting from the basin-wide phosphorus restrictions. The two Arkansas counties account for roughly 82 percent of the poultry production in the Illinois River Basin, the base solution. In addition, this region of the River Basin accounts for roughly 88 percent of the phosphorus in runoff that is generated throughout the Illinois River Basin.

The last item to consider in this section is the opportunity cost per ton of litter reduction for phosphorus restrictions. These data are shown in Table 10. Notice that costs range from $52 per ton of litter reduced to $65 per ton of litter removed. These per-ton costs reflect the assumption that land-based application of litter is the only alternative for disposal of litter generated in the basin and provide a benchmark for comparing alternative options of dealing with litter throughout the basin, including export.

Table 10
Per-Ton Opportunity Cost of Litter Reduction for Phosphorus Restrictions

	Opportunity Cost Per Ton of Litter
20 percent reduction	$52
50 percent reduction	57
0.05 mg/L Target	61
0.037 mg/L Target	63
80 percent reduction	64
0.02 mg/L Target	65

Limits of Soil Test Phosphorus as an Alternative Target

Some administrators in Oklahoma advocate a phosphorus policy based on limiting the amount of phosphorus per acre in the soils. This approach includes an assessment of phosphorus levels in the soil on a per-unit basis; however, the implications of using soil test phosphorus limits as a surrogate measure for phosphorus in runoff for the Illinois River Basin is unknown. Alternatively, what soil test phosphorus limits would be consistent with three different phosphorus target levels currently being discussed for the Illinois River Basin?

The distribution of soil test phosphorus levels within region k is described by:

$$\mathrm{STP}_k^z + N_k^z = X_k^z \tag{11}$$

where: $N_k^z \equiv$ value of phosphorus added to the soil per acre in region k, political jurisdiction z

$X_k^z \equiv$ total amount of phosphorus in the soil per acre in region k, political jurisdiction z.

$\mathrm{STP}_k^z \equiv$ initial level of phosphorus in the soil per acre in region k, political jurisdiction z.

$$(z = 1, 2)$$

$$(\mathrm{k} = 1, \ldots, \mathrm{K}).$$

The limit of soil test phosphorus per acre is given as:

$$X_k^z \leq \overline{X}_k^z \tag{12}$$

$\overline{X}_k^z \equiv$ maximum amount of phosphorus in soil per acre in region k, political jurisdiction z.

$$(z = 1, 2)$$

$$(\mathrm{k} = 1, \ldots, \mathrm{K}).$$

The value of $\overline{X}_k^z$ is set by a policy maker while STP_k^z is an estimated value of phosphorus in the soils within the Illinois River Basin.

The total amount of phosphorus added to the soil in region k from poultry litter application is based on the number of acres to which litter is applied times the additional amount of phosphorus added per acre. Let L_{kz}^z denote the total acres to which phosphorus has been added. Then:

$$L_{kz}^z = \sum_{i=1}^{I} L_{ki}^z \tag{13}$$

where constraint (5) is satisfied.

The total amount of phosphorus added to the ground in region k, Q_k^z, can be defined as

$$Q_k^z = N_k^z L_{kz}^z. \tag{14}$$

Notice that equation (14) is a nonlinear relationship. The following expression is used to approximate Q_k^z.

$$Q_k^z = \overline{L}_{kz}^z N_k^z + \overline{N}_k^z L_{kz}^z - \overline{L}_{kz}^z \overline{N}_k^z \tag{15}$$

where: $\overline{L}_{kz}^z$ ≡ initial value of land area covered with phosphorus, and

$\overline{N}_k^z$ ≡ initial value of phosphorus added to the soil per acre.

If we define $\overline{Q}_k^z = \overline{L}_{kz}^z \overline{N}_k^z$, then the equation can be rewritten as:

$$Q_k^z = \overline{L}_k^z N_k^z + \overline{N}_k^z L_k^z - \overline{Q}_k \tag{16}$$

$(k = 1, \ldots, K)$

$(z = 1, 2)$.

The final step requires defining the sources of phosphorus generation that is applied to each region and theoretically includes both commercial fertilizer and poultry litter. The total amount of phosphorus is:

$$Q_k^z = \sum_{i=1}^{I} \left[\left(1 - \beta_{ki1}^z\right)\left(1 - \alpha_{ki1}^z\right)\theta_{ki1}^z M_{ki}^z \right] \tag{17}$$

$(k = 1, \ldots, K)$

$(z = 1, 2)$.

Equation (9) is now replaced by equations (12), (16), and (17). In addition, equation (8) is used to calculate the total amount of phosphorus in runoff.

The initial per acre soil test phosphorus values for each of the counties included in the modified optimization model are shown in Table 11. These values were based on soil test analyses done by the cooperative extension service offices with Oklahoma State University and the University of Arkansas.

Table 11
Initial Soil Test Values

County	Lbs Per Acre
Adair (OK)	215
Cherokee (OK)	55
Delaware (OK)	233
Benton (AR)	307
Washington (AR)	272

Soil test phosphorus limits ranging from 500 lbs per acre down to 320 acres per acre were imposed for all production regions in the model. The corresponding basin-wide amounts of total phosphorus in runoff for each the respective model solutions are shown in Table 12.

Table 12
Soil Test Phosphorus Limits and Phosphorus in Runoff

Soil Test Phosphorus Limit (lbs/Acre)	Total Phosphorus In Runoff for Illinois River Basin (tons)
500	154
400	154
350	154
325	139
320	96

The key observation from this exercise is that the total phosphorus in runoff for the Illinois River Basin are well above the corresponding amounts for the three alternative basin-wide phosphorus limits discussed by officials from Oklahoma and Arkansas for the Illinois River Basin. The optimization model was again resolved with the three different basin-wide phosphorus limits imposed to identify the corresponding per acre soil test phosphorus values for each county or production region in the model. These results are shown in Table 13.

Table 13
Per Acre Soil Test Phosphorus Values For Basin-Wide Phosphorus Limits for the Illinois River Basin

County	Base Solution (lbs/acre)	0.02 mg/L (lbs/acre)	0.037 mg/L (lbs/acre)	0.05 mg/L (lbs/acre)
Adair (OK)	226	220	220	220
Cherokee (OK)	59	58	58	58
Delaware (OK)	249	249	249	249
Benton (AR)	327	321	322	325
Washington (AR)	290	282	282	282

The results show that the basin-wide targets for phosphorus in runoff cannot be achieved by imposing a per-acre limit on soil test phosphorus. Daniels et al. (1999) reports that for lands with high soil test phosphorus levels, appreciable amounts of soluble phosphorus can exist in runoff water and can significantly impact water quality in receiving streams and lakes. More specifically, it has been shown in recent research that an examination of the top one inch of a soil profile shows that the concentration of phosphorus increases as soil test phosphorus increases. These findings have led some soil scientists and the Natural Resources Conservation Service to recommend a soil test phosphorus limit of 300 pounds per acre as an example.

Daniels et al. (1999) also attempt to address the rationale of a soil test phosphorus limit such as 300 pounds per acre. They argue that such a limit is reasonable because it represents more than the available phosphorus needed for crop production. Moreover, this value is hopefully low enough to minimize phosphorus in runoff that will create water quality problems. But the environmental impacts of a soil test phosphorus limit of 300 pounds, for example, have not been established. The complex set of variables governing the transfer of phosphorus from land surface to aquatic systems makes its environmental impact difficult to assess.

The existing evidence suggests that soil test phosphorus may serve as an indicator of situations where a significant concentration of dissolved phosphorus could be found in runoff, but it does not offer any indication of the amount or rate of runoff that may be generated for a particular set of conditions. The total amount of phosphorus leaving a field is a function of the runoff phosphorus concentration and the runoff volume. The real issue in this matter is not phosphorus concentration in the runoff from the edge of any particular field, but the total phosphorus load transported to the stream or lake of an entire watershed. The maximum amount of phosphorus that can be assimilated in a watershed without causing eutrophication depends on several factors such as soil test phosphorus levels, distance from significant streams, slope, soil types, buffer strips, type of crop or forage cover, as well as the characteristics of the streams or lakes themselves.

ECONOMIC IMPACT ASSESSMENT

To assess the economic impact of implementing the proposed basin-wide phosphorus reduction policies on the counties comprising the Illinois River watershed, an IMPLAN analysis was conducted utilizing data from the USDA and Bureau of Economic Analysis adjusted according to the preceding model results. IMPLAN is modeling software that is based on the theories and assumptions of input-output analysis (Elrod, 1969; MIG, Inc., 2004). It must again be mentioned that reductions in poultry litter in this research effort are made only by a corresponding reduction in poultry production and processing in the study region; alternative methods of reducing poultry litter in the basin, such as transport from the river basin boundaries or processing into products that may be moved from the watershed, are not considered. Detailed analyses for the two Arkansas counties, the three Oklahoma counties and all five counties combined were conducted and are reported in the following sections.

Arkansas Only Region

The Arkansas Only (Benton and Washington counties) economy consists of 190,447 jobs where employees earn $5.4 billion in salaries and produce $8.2 billion in value added production. The poultry production and processing sectors are responsible for over 10 percent of those jobs, income, and value added production. These sectors contribute 21,438 of those jobs, $607 million in income, and $823 million in value added.

The six scenarios examined lead to six different levels of reduced economic activity, brought on by changes in the poultry processing sector that filter throughout the economy. These losses, shown in Table 14, represent 10 to 60 percent reductions in the poultry industry's direct contribution to the local economy. Table 15 shows the final level of economic activity in the region associated with current (1999) conditions and under six phosphorus limitations. These changes represent a reduction of one to six percent in overall economic activity in the region.

While the impact to the overall economy may seem small, six general sectors of the economies felt close to ninety percent of all impacts. Those sectors are Processed Meats, Poultry and Egg Production, Wholesale and Retail Trade, Miscellaneous Services, Financial/Real Estate and Health Services.

Table 14
Reductions in Contributions of Economic Activity by the Poultry Industry Due to Six Different Phosphorus Limitation Scenarios in the Arkansas Only Region

Scenario	Employment	Income	Value Added
20% Less	-2,038	$-57,595,180	$-78,194,196
50% Less	-6,793	-191,655,646	-260,201,670
0.05 mg/l	-8,924	-252,134,319	-342,310,639
0.037 mg/l	-11,279	-318,874,983	-432,623,245
80% Less	-11,985	-338,583,723	-459,678,846
0.02 mg/l	-12,976	-367,197,811	-498,443,995

Table 15
Final Levels of Economic Activity in the Economy Under the Current (Baseline) Scenario and Under Six Phosphorus Limit Scenarios in the Arkansas Only Region

Scenario	Employment	Income	Value Added
Baseline	190,477	$5,440,577,000	$8,299,776,000
20% Less	188,440	5,382,981,820	8,221,581,804
50% Less	183,684	5,248,921,354	8,039,574,330
0.05mg/l	181,553	5,188,442,681	7,957,465,361
0.037mg/l	179,198	5,121,702,017,	7,867,152,755
80% Less	178,492	5,101,993,277	7,840,097,154
0.02mg/l	177,501	5,073,379,189	7,801,332,005

Oklahoma Only Region

The Oklahoma Only (Adair, Cherokee, and Delaware counties) economy consists of 39,140 jobs where employees earn $865 million in salaries and produce $1.2 billion in value added. The poultry production sector is responsible for over three percent of those jobs, income, and value added. These sectors contribute 1,445 of those jobs, $24 million in income, and $35 million in value added.

The six scenarios examined lead to only two different levels of reduced economic activity, brought on by changes in the poultry production sector that filter throughout the economy. These losses, shown in Table 16, represent 21 to 27 percent reductions in the poultry industry's direct contribution to the local economy. Table 17 shows the final level of economic activity in the region associated with current

(1999) conditions and under six phosphorus limitations. These changes represent a reduction of one-half to one percent in overall economic activity in the region.

Table 16
Two Levels of Reductions in Contributions of Economic Activity by the Poultry Industry Due to Six Different Phosphorus Limitation Scenarios in the Oklahoma Only Region

Scenario	Employment	Income	Value Added
20% Less & 50% Less	-304	-5,168,036	$-7,522,283
0.05mg/l, 0.037 mg/l, 80% Less, 0.02mg/l	-392	-6,657,836	-9,690,747

Table 17
Two Final Levels of Economic Activity in the Economy Under Current (baseline) Scenario and Under Six Phosphorus Limit Scenarios in the Oklahoma Only Region

Scenario	Employment	Income	Value Added
Baseline	39,140	$865,312,000	$1,219,205,000
20% Less & 50% Less	38,836	860,143,964	1,211,682,717
0.05mg/l, 0.037 mg/l, 80% Less, 0.02 mg/l	38,748	858,654,164	1,209,514,253

Although the impact to the overall economy may seem small, six areas of the economies felt close to 84 percent of all impacts. Those sectors are Poultry and Egg Production, Utility Services, Financial/Real Estate, Transportation and Communication, Wholesale and Retail Trade, and Construction and Health Services.

Combined Arkansas-Oklahoma Regional Study

The Arkansas-Oklahoma Regional (Benton, Washington, Adair, Cherokee, and Delaware counties) economy consists of 229,616 jobs where employees earn $6.3 billion in salaries and produce $9.5 billion in value added. The poultry production and processing sectors are responsible for over 10 percent of those jobs, income, and value added. These sectors contribute 26,151 of those jobs, $711 million in income, and $969 million in value added. [1]

[1] Note that there are slight differences in levels of impacts from the Arkansas-Oklahoma combined region and the sum of the Arkansas Only and Oklahoma Only. This is a frequent occurrence in IMPLAN analyses and can be attributed here to differences in types of poultry (production vs. processing) activity and differences in regional purchasing coefficients in the two sub-regions.

Table 18
Reductions in Contributions of Economic Activity by the Poultry Industry Due to Six Different Phosphorus Limitation Scenarios in the Combined Arkansas-Oklahoma Region

Scenario	Employment	Income	Value Added
20% Less	-2,957	$-80,251,929	$-109,449,416
50% Less	-8,145	-221,003,233	-301,409,259
0.05 mg/l	-10,695	-290,202,971	-396,785,453
0.037 mg/l	-12,876	-349,355,178	-476,458,585
80% Less	-14,041	-380,966,968	-519,571,526
0.02 mg/l	-15,124	-410,379,763	-559,685,316

Table 19
Final Levels of Economic Activity in the Economy Under Current (baseline) Scenario and Under Six Phosphorus Limit Scenarios in the Combined Arkansas-Oklahoma Region

Scenario	Employment	Income	Value Added
Baseline	229,616	$6,305,887,000	$9,518,978,000
20% Less	226,659	6,225,635,071	9,409,528,584
50% Less	221,471	6,084,883,767	9,217,568,741
0.05 mg/l	218,921	6,015,684,029	9,122,192,547
0.037 mg/l	216,740	5,956,531,822	9,042,519,415
80% Less	215,575	5,924,920,032	8,999,406,474
0.02 mg/l	214,492	5,895,507,237	8,959,292,684

The six scenarios examined lead to six different levels of reduced economic activity, brought on by changes in the poultry processing sector that filter throughout the economy. These losses, shown in Table 18 represent 11 to 58 percent reductions in the poultry industry's contribution to the local economy. Table 19 shows the final level of economic activity in the region associated with current (1999) conditions and under six phosphorus limitations. These changes represent a reduction of one to seven percent in overall economic activity in the region.

While the impact to the overall economy may seem small, six areas of the economies felt close to eighty-eight percent of all impacts. Those sectors are Processed Meats, Poultry and Eggs, Wholesale and Retail Trade, Miscellaneous Services, Financial/Real Estate, and Health Services.

Summary and Conclusions

The Illinois River Basin in eastern Oklahoma and northwest Arkansas is an example of a region where significant growth in poultry production has been accompanied by water quality problems. The primary management concern in the basin is to reduce phosphorus levels in surface runoff in areas where poultry litter is applied to agricultural land. Existing data suggests that there is a continuing decline in the quality of water in the Illinois River Basin and efforts have focused on developing and implementing a phosphorus standard.

The limits imposed on phosphorus in runoff for the entire basin ranged from a 20 percent reduction in base-level values from the initial calibrated model solutions to the target amount of phosphorus corresponding to a concentration level of 0.02 mg/L. The opportunity cost for the entire basin was shown to range from approximately $1.5 million with the 20 percent reduction in phosphorus to $7.7 million with the limit corresponding to concentration of 0.02 mg/L. The difference between these two limits represents a 517 percent increase in the opportunity cost for the entire river basin. A regional disaggregation of the opportunity costs reveals that the majority of these costs were borne by the sub-basin located in Arkansas. It was also shown that the opportunity cost per ton of litter reduction for the phosphorus restrictions ranged from $52 per ton of litter reduced to $65 per ton of litter reduced. These costs reflect the assumption that land-based application is the only alternative for disposal of litter in the basin and provide a benchmark for comparing alternative options for dealing with litter. An economic impact assessment of the basin-wide phosphorus limitations was also conducted for the Arkansas counties only, the Oklahoma counties only, and all five affected counties. It was shown that economic activities related to poultry grower activity were substantial in the region. Moreover, it was shown in this analysis that the more restrictive phosphorus limits imposed relatively large losses on the regional economy.

Policy makers have also advocated a phosphorus policy based on setting limits on the amount of phosphorus in the soils per acre. This analysis was designed to address the question of whether soil test phosphorus limits would be consistent with the three different phosphorus concentration levels currently being discussed for the Illinois River Basin. The results reported in this research showed that the basin-wide targets for phosphorus could not be achieved by imposing a per-acre limit on soil test phosphorus, nor could they be approached without serious consequences to economic activities in the study area.

The major caveat for this research is that the only alternative for disposal of poultry litter generated in the Illinois River Basin considered is land-based applications. The only response to achieve the basin-wide limits imposed on phosphorus present in runoff is to reduce poultry production as a way to reduce poultry litter applied to the land. Although several research and implementation initiatives are currently underway to utilize poultry litter, alternative methods of reducing poultry litter in the river basin are not considered. Some of these options include transport from the river basin boundaries by a non-profit third-party enterprise known as the Ozark Litter Bank (Goodwin, 2004) or processing into energy or value-added products that may be moved from the river basin. Thus, the opportunity costs of the alternatives examined in this research may overstate what these costs would be with additional alternatives for disposing of poultry litter generated within the Illinois River Basin. The process of identifying additional alternatives to land application of poultry litter in nutrient-surplus watersheds is currently being evaluated alongside the transport of litter out of the watershed. Determining the respective opportunity costs of a range of limitations on phosphorus present in runoff for the Illinois River Basin is currently underway.

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APPENDIX

The empirical version of the biological response function equation (4) is adapted from functions derived by Gonzalez-Alcorta, Dorfman, and Pesti (1994). The weight gain function developed by these authors is a function of energy and protein levels and can be written as follows:

$$W_k^z = B_{0k}^z + B_{1k}^z E_k^z + B_{2k}^z \left(E_k^z\right)^2 + B_{3k}^z D_k^z + B_{4k}^z \left(D_k^z\right)^2 \qquad \text{(A.1)}$$

where: E_k^z ≡ energy level of a production unit in region k, political jurisdiction z, and

D_k^z ≡ protein in diet of a production unit in region k, political jurisdiction z.

A number of steps can be taken to restate equation (A.1) in terms of feed intake that reflects the proportion of each ingredient in the cost minimization solution and also reflects the corresponding energy and protein content values. Assume that the amount of each ingredient in the cost minimizing diet is written as:

$$X_{kj}^z = \bar{x}_{kj}^z F_k^z \qquad \text{(A.2)}$$

where: $\bar{x}_k^z$ ≡ fixed proportion of ingredient j in the diet for a broiler production unit in region k (this is determined from the integrator's dietary cost minimization model),

X_k^z ≡ amount of ingredient type i in the diet for a broiler production unit in region k, and

F_k^z ≡ feedstuff intake for a broiler in a production unit in region k.

In general, the energy and protein contents in a broiler diet can be written as follows:

$$E_k^z = \sum_{j=1}^{J} \varepsilon_{kj}^z X_{kj}^z \qquad \text{(A.3)}$$

$$D_k^z = \sum_{j=1}^{J} \varphi_{kj}^z X_{kj}^z \qquad \text{(A4)}$$

where: φ_{kj}^z ≡ protein content per unit of the zth ingredient in broiler diet for a broiler production unit in region k, and

ε_{kj}^z ≡ energy content per unit of zth ingredient in broiler diet for a broiler production unit in region k.

Equation (A.2) can be used to rewrite equations (A.3) and (A.4) as follows:

$$E_k^z = \mu_k^z F_k^z \tag{A.5}$$

$$D_k^z = \Phi_k^z F_k^z \tag{A.6}$$

where:

$$\mu_k^z = \sum_{j=1}^{J} \varepsilon_{kj}^z \bar{x}_{kj}^z$$

$$\Phi_k^z = \sum_{j=1}^{J} \varphi_{kj}^z X_{kj}^z.$$

The parameter μ_{kj}^z can be interpreted as the "weighted average" value of the energy content per unit of the feedstuff while Φ_{kj}^z is the "weighted average" value of protein content per unit of feedstuff. (Recall that weights are the proportional factors $\bar{x}_{kj}^z$.)

Equations (A.5) and (A.6) can be used to rewrite equation (A.1) as follows:

$$W_k^z = \varphi_{1k}^z + \varphi_{2k}^z F_k^z + \varphi_{3k}^z \left(F_k^z\right)_2 \tag{A.7}$$

where:

$$\varphi_{1k}^z = B_{0k}^z$$

$$\varphi_{2k}^z = B_{1k}^z \mu_k^z + B_{3k}^z \Phi_k^z$$

$$\varphi_{3k}^z = B_{2k}^z \left(\mu_k^z\right)^2 + B_{4k}^z \left(\Phi_k^z\right)^2.$$

The broiler diet ingredients and their respective proportions are shown in Table A.1, while the metabolizable energy and protein values are shown in Table A.2. These data are used to determine μ_k^z and Φ_k^z in equations (A.5) and (A.6).

Table A.1
Broiler Finisher Diet

Ingredient	Percent
Yellow Corn (NRC)	72.3450
Soybean Meal (NRC)	18.7820
Meat & Bone (NRC)	4.9180
Poultry Oil (NRC)	2.5130
Limestone	0.5833
Salt	0.3738
Broiler Vitamin (PWW)	0.2000
Trace Mineral (PWW)	0.1000
Threonine	0.0820
DL Methionine 98	0.0528
Lysine HCL 98%	0.0499

Table A.2
Broiler Energy and Protein Values

Ingredient	Metabolizable Energy (kcal/kg)	Protein (%)
Yellow Corn (NRC)	3,350	8.5
Soybean Meal (NRC)	3,500	94.1
Meat & Bone (NRC)	2,150	50.4
Poultry Oil (NRC)	2,360	81.0
Limestone	--	--
Salt	--	--
Broiler Vitamin (PWW)	--	--
Trace Mineral (PWW)	--	--
Threonine	--	--
DL Methionine 98	3,606	57.52
Lysine HCL 98%	3,607	94.4

The biological response function for broiler weight gain is:

$$W_k = -0.2068 + 4.3219F_k - 2.0507F_k^2. \qquad \text{(A.8)}$$